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*Can vernacular architecture be integrated within
contemporary sustainable building design tech-
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SID: 3304160009

SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Building Design

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Abstract

This dissertation was written as a part of the MSc in Energy Building Design at the International Hellenic University.

Nowadays, one of the most pressing objectives towards a sustainable development is to retain a sustainable building practice. Vernacular architecture has been long admired for its so-called energy efficiency and its valuable lessons advocated that should be fulfilled in contemporary design. The main purpose of this study is to identify whether vernacular building techniques can be incorporated in contemporary building practice, in terms of sustainability.

The work starts from the categorization of vernacular architecture based on Köppen's climate classification. Basic typology concerning bioclimatic strategies implemented in syntax, morphology and construction is composed. Proceeding, a more in-depth analysis of the two most popular earth architecture techniques is conducted, analyzing the properties, availability, cost, code provision and recent developments in the field. In addition, barriers against further penetration of earth techniques in contemporary building practice are researched. Finally, contemporary projects incorporating vernacular earth techniques as loadbearing masonry are analyzed to find whether sustainability's terms are met.

The findings reveal that, vernacular earth architecture is not a priori a profound sustainable solution, but design, location, availability and use of resources, technology and inclusion of local builders play a vital role. It can be suggested, that under specific terms such techniques can be a sustainable solution for societies on crisis.

Acknowledgement

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Lastly, I must express my very deep gratitude to my parents, my spouse and friends for providing me with unfailing support and continuous encouragement throughout my years of study. Thank you.

Potouridou Chrysoula

30/6/2018

To my lovely daughters...

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1 Introduction

- What is vernacular architecture and what are its virtues?

Vernacular architecture is the accumulation of technical, practical and theoretical wisdom expressed in the built form, from the beginning of times till the industrialization. Humankind was called to survive in extreme climates, dangerous territories, with lack or plethora of flora and fauna, restricted resources and lack of technical means. From the humble hut to the longhouse, vernacular architecture serves not only the basic human need for survival but also man's social and cultural need for social development.

Specific virtues have been attributed to vernacular architecture. Avoiding any inclination to romantic nostalgia of the past, vernacular architecture has been proven to answer to man's basic accommodation needs, providing a shelter from the hostile environment, with the most efficient way in terms of energy, technology and resources. A sincere devotion to the locale and to the specific microclimate of the region, the use of any material available only at a short-logical distance from the site, the exploitation of the built form to serve practicability, and the harmonious coexistence of the various built forms are some of the characteristics of the worldwide vernacular architecture. Building of this type conduces to a state of balance with nature instead of dominating it.

However, as technology evolved traditional building techniques were abandoned. Moreover, radical alteration of social forms, norms and lifestyles changed man's expectations and needs on the built form, being evident in the most basic built form; the house.

- What are the attributes of contemporary architecture, what are its limitations and needs?

Contemporary architecture refers to the architecture of the 21st century. It compiles diverse styles, -from modernism to deconstructivism-, and although an integrated specific style cannot be spotted, it has a global character [1].

Contemporary architecture seems to embody many of the virtues and mottos of modern architecture. Clean dynamic lines, spaciousness, continuous flow of space, integration of indoors and outdoors, maximum of light and unobstructed view are still embraced from contemporary architects. Moreover, the repulsion to any determinism followed by

function, as well as an eagerness to explore the plethora of new technologies seem to characterize contemporary architecture, which is led by few architects working worldwide.

Although regionalism and traditional building techniques had somehow become obsolete, in recent years a rise of the global environmental consciousness has made architects to review their practice. This rise of environmental consciousness is attributed to energy crisis and extended environmental challenges that urge policy makers, designers and interested parties to revise their practice [2], [3]. The new trend, -the quest for energy efficiency and sustainability-, has forced architects to reconsider vernacular architecture and its lessons, in an effort to find answers and solutions that can be applied in contemporary architecture and building practice.

- Can vernacular architecture answer/help/cover problems/limitations/needs of contemporary architecture, in terms of sustainability?

The question on whether vernacular architecture can be the answer to the limitations and needs of contemporary one, in terms of sustainability, is not an easy one. Sustainability refers to sustainable development, which incorporates three domains; environment, economy and society. So, vernacular architecture should be studied and integrated in order to fulfil all the aforementioned terms.

In the current research, a literature review is carried out in order to investigate the factors that affect vernacular architecture, the linkage of vernacular architecture to energy efficiency and finally the deficiencies of contemporary approach to vernacular architecture. In the third chapter, a basic categorization and analysis of vernacular architecture based on Köppen's classification system is attempted, focusing on residences of preindustrial peasant societies. In the fourth chapter, a more in-depth survey on specific vernacular building techniques is conducted (adobe, rammed earth), focusing on their properties, availability, cost, code provision and recent developments to meet contemporary design challenges. In the fifth chapter the barriers for future penetration of vernacular earth building techniques into contemporary sustainable building practice are investigated. Finally, contemporary projects incorporating earth techniques (adobe and rammed earth) are presented, evaluating their environmental, social and economic parameters.

2 Literature Review

2.1 Factors affecting vernacular architecture

Vernacular architecture has been formed through centuries and generations, adapting to specific climatic, geographical, social, economic and cultural contexts. It is not the result of a one-man design, plan or idea, but rather the accumulated wisdom and expertise of centuries of trials and alterations of a basic plan, design or construction method, passed from generation to generation, to local builders and indigenous people [4].

Many factors have been proven to form and affect vernacular architecture. The material ones; climatic conditions, geographical restrictions, availability of resources, and the immaterial ones; ethics, social patterns, lifestyle, culture, religion all connecting to the survival of man in its natural and social environment.

Early studies on vernacular architecture investigated the aforementioned relationship; vernacular architecture and natural-social environment, but in rather loose terms. Many of them got stuck in a mere documentation of the vernacular forms, planning and elements, while a crucial question back at those days was the deterministic role of the natural environment in the expense of social and cultural values [5].

2.1.1 Material factors

In the most elaborated and extensive document on vernacular architecture, ‘The Encyclopedia of Vernacular architecture’, Paul Oliver examines the relationship between climate and vernacular architecture. The extended research by over 750 authors from 80 countries, concluded in a correlation between the built environment and the regional climatic, geographic and technological restrictions [6]. Surprisingly, although there is a whole chapter entitled “Environment”, there is no reference on the term “sustainability”.

Similarly, Coch, H. studied the relationship between form and climate. Categorizing the climate, a vernacular response of a plethora of cultures was found on specific climate context [7]. In more detail, Coch distinguishes three basic and two further quite exemplary types of climates (*basic*; cold, dry warm, wet warm, *exemplary*; windy, complex). She observed practically identical architectural solutions that have been developed in

highly resembling climates, yet with different cultures and at remote geographical locations.

2.1.2 Immaterial factors

For years climatic, geographical or technological determinism have been widely accepted among architects and cultural geographers. However, Amos Rapoport, in his study on the factors affecting house form, one of the major studies on the issue, questioned the importance of climate, materials, construction and technology and their determining role [8]. According to him, there are situations where social, cultural and religious values take precedence over climatic, geographical or technological restrictions. Thus, man builds not only to control his physical environment, but also to control his inner, social and religious environment. Rapoport argued that the most important factors that affect built form are:

1. Some basic needs (fresh air (smell/smoke), desired light levels, comfort level of heating, eating requirements, sitting habits, concept of poverty and gaining a livelihood).
2. Family structure (simple/extended, monogamy/polygamy, patriarchal/matriarchal).
3. Position of women.
4. Privacy (sex and shame, feelings of personal worth, territoriality).
5. Social intercourse.

On the same frame, Sayigh et al., in a study of Iranian houses, showed that vernacular architecture addressed not only the survival against adverse climatic conditions, but also ways to organize the living spaces, so as to incorporate the strict Islamic teachings and the place of women in society [9]. The spatial hierarchy (public/semi-public/private spaces), the distribution of spaces in ground and upper floors, the view to public and semi-public spaces, the access in Iranian house meet not only climatic but mainly cultural needs.

2.2 Vernacular architecture and energy efficiency

There is a paradox on vernacular architecture; although its techniques and features are abandoned and neglected, it is widespread praised for its so called excellent energy performance and efficient planning, use of resources, building techniques et cetera. Many

studies till the recent past focused on the qualitative analysis of the factors that contribute to the energy efficiency of vernacular architecture, while more recently the focus shifted to a quantitative analysis of the aforementioned features (e.g. [10]–[14]), examined even by field measurements and comprehensive research (e.g. [15]–[17]). The majority of these studies have as an objective (among others) to extract techniques that could be adopted by contemporary architecture. In this subchapter, the literature review focuses on studies that investigate the relation of vernacular architecture to energy efficiency.

S.S. Chandel et al. in their study identified the main parameters incorporated in vernacular architecture, that contribute to its' sufficient energy performance. These are the building/roof materials, the light/heavy construction, the proper orientation and space planning, the openings and sunspaces [18]. Moreover, the study suggests that contemporary architecture can benefit in terms of energy efficiency and thermal comfort from the inclusion of vernacular environmental controls and passive solar features in contemporary design.

On the same frame, Liu et al. and Priya et al. counsel to take advantage of vernacular building techniques in contemporary architecture in order to achieve comfortable indoor conditions in a more energy efficient manner [19], [20]. More specifically, Priya et al. made a quantitative analysis of vernacular architecture of the coastal belts of Nagapattinam, concluding that its natural and passive methods manage to retain indoor thermal comfort irrespective of the outdoor climatic conditions.

Foruzanmehr, A., & Vellinga, M. in their study on the Iranian passive cooling strategies concluded that these can retain comfortable temperatures in the house, but only to a certain degree and with specific restrictions [15]. Moreover, they stated that the sufficient energy performance of a specific vernacular building element does not imply arbitrarily that the whole vernacular tradition can be sustainable.

Dili et al. used field measurements to examine the indoor thermal comfort of a typical traditional building in Kerala. The research deduced that the building corresponds satisfactorily to the external harsh climatic conditions, by exploiting a highly insulative building envelope and maintaining controlled and continuous airflow to deal with large diurnal variation of outdoor temperatures and humidity [21].

Desogus et al. in his study on Sardinian vernacular architecture, stated that it presents building characteristics and passive systems that correspond to the specific regional bio-

climatic needs of Sardinia [22]. According to the findings, thermal mass effect is the most predominant strategy that contributes to the stabilization of indoor temperature, evident in the thick, heavy earthen or stone walls. However, additional sources of heat, such as stove, were necessary to guarantee comfort conditions. Passive solar heating was not implemented in Sardinian architecture, due to absence of insulation, small openings and low airtightness.

2.3 Deficiencies on vernacular architecture approach

In a very ingenious article, Vellinga, M. points out that the approach of vernacular architecture by academics is deficient and incorporates some shortcomings that act counterproductively and rather discourage penetration of vernacular architecture in contemporary design [5]. More specifically, Vellinga points out that vernacular architecture approach hinders four shortcomings;

1. An environmental focus; many studies investigate only the environmental sustainability of vernacular architecture at the expense of social/cultural/economic sustainability (e.g. [11], [14]).
2. A technological bias; many studies focus only on the efficient management of materials, technology and planning of vernacular architecture, driving arbitrary conclusions.
3. A romanticized approach; many studies are characterized by a romantic nostalgia of the past, approaching the vernacular with sentimentalism and peremptorily overpraising its “superior” sustainability. Often authors ascribe the abandonment of the vernacular practice to the powerful influence of Western culture and modernization, a theory that is not based on extensive research (e.g. [23], [24]).
4. Essentialist representations; many writings tend to arbitrarily generalize conclusions for the vernacular architecture of a whole region, let alone vernacular in general, driven by the examination of a very specific vernacular example (e.g. [14], [25]).

Aligned with Vellinga, Hanita et al. in a study on vernacular and contemporary houses in Oman, pointed the importance of human factor and behavior for the successful application of the vernacular wisdom [26]. A comparative analysis of both vernacular and conventional systems, showed that climatically correct design and use of vernacular

techniques can be surpassed by no-compatible human attitude. Such conclusions demonstrate among others the importance of social and cultural viability of vernacular architecture in contemporary context.

3 Vernacular architecture

In order to adequately answer to the main question of this thesis, that is whether vernacular architecture can be integrated in contemporary design or not, it is crucial to examine the essence of vernacular, the factors under which it is formed and the different types, construction methods, materials that are used.

However, building history and documents as vast as the history of man, are impossible to be thoroughly examined. Not only the material is vast, but is also not recorded in any uniform way, let alone the non-uniform quality of the sources. For the purpose of this thesis, “vernacular” is examined in terms of sustainability, in order to extract valuable building attributes and techniques able to be integrated in contemporary design. In that frame, the research will focus on these features of vernacular architecture which seem most universal and which seem to correspond well to specific environmental contexts.

In this chapter, vernacular architecture is investigated based primarily on the works of Oliver, Paul; *The Encyclopedia of Vernacular Architecture* and *Dwellings. The house across the world*, and Rapoport, Amos; *House form and culture*. The form of a basic typology of vernacular building tradition based on climate is attempted, taking into consideration syntax, morphology and construction.

Nevertheless, Rapoport, A. on his study on house form after explicitly examining the factors forming the house, concludes that there is no point on classifying buildings types based on different factors (physical, socio-cultural etc.). There is no imposing factor, nor a strict causal relationship between the given context and final house form. According to him, the researcher must be very careful not to speak of determining forces, but rather coincidences that best align with the complexity of the different variables. Acknowledging Rapoport’s repulsion on strict imposing factors, it has to be stated that the derived typology as proposed by this research is not deterministic nor explicit and definitely doesn’t imply that climate is the only predominant force that forms vernacular.

3.1 Area of study

Building form, as complex and multidimensional as the history of man, can be categorized in buildings belonging to the grand design tradition and those of the folk tradition.

Monuments or buildings that belong to the grand design tradition are built to impress, designed by the peer designers of their times. On the contrary, folk tradition is related to the culture of the majority and represents the bulk of the built environment.

According to Rapoport, A. folk tradition incorporates two types of buildings, the primitive and vernacular. Primitive are the buildings that are produced by primitive societies, as defined by anthropologists. In such societies, there is a diffuse knowledge of everything by all, there is no technical vocabulary, there is little specialization and in short terms everyone has the technical knowledge and the capability to build his own dwelling. In such societies, tradition is catalytic; certain forms are predetermined and strongly resist change, leading to a model completely uniform and dwellings fully identical.

The distinctive point between primitive and vernacular buildings is the insertion of building tradesmen in the construction process. Vernacular buildings can be further divided in 2 categories; preindustrial vernacular and modern vernacular. In the preindustrial vernacular everyone in the society still shares common building types and ways of construction, but there are building tradesmen. The owner is not merely a consumer, but he participates in the building design and construction process, while owner and tradesman share common technical and design vocabulary and style.

Preindustrial vernacular has the following characteristics that distinguish it from primitive and modern vernacular[8];

- a. More individual variability and differentiation than in primitive buildings. The type remains the same, but individual specimens are modified.
- b. Additive quality. There is no closed, final form but rather the ability to accept changes and additions in the passage of time. A characteristic absent in modern vernacular.
- c. The type and the construction process are specified by tradition, which is shared by everyone.

This tradition is the regulator of the building activity, has the force of law honored by everyone and it is thus obeyed and accepted, acting as discipline and collective control. Aesthetics are linked to the tradition and are not specially created for each dwelling. However, the size, the planning and the relation to the site are set in collaboration between the owner and the craftsman. It is the power of the aforementioned tradition that vitalizes preindustrial vernacular architecture. Without this, there is no reliance on the

accepted norms, aesthetics, building types and lifestyle and that's when institutionalization begins, with the introduction of pattern books, codes, regulations and zoning rules.

Tradition as a regulator in design and building process has disappeared for a number of reasons according to Rapoport, A.;

- a. The number of building types was largely increased, many of them being too complex to comply with traditional norms.
- b. The common shared value system and goals accepted by both designers and public were lost.
- c. Traditional forms were no more adequate as society puts a premium on novelty and originality.

This study will focus on the examination of preindustrial vernacular architecture and more specifically on peasant architecture, since it is most advanced than primitive, in terms of form, planning and construction methods and resembles more the socio-cultural and economic challenges featured today.

3.2 Method of study

Climate, geography, flora and fauna, economics, resources and sociocultural parameters are some of the factors affecting vernacular architecture. On the long history, several researches approaching the study of vernacular are conducted, using as primal defining factor topography or culture, with only a small minority of those attempting to examine vernacular worldwide [6], [27], [28]. Since, the principal reason for the present-day revival and interest on vernacular practices is their so called 'energy efficiency', climate has been chosen to be the primary factor for the investigation and analysis of vernacular. (For this purpose the anticlimactic solutions and the predominance of criticality in severe contexts will be largely neglected). In that sense, typical solutions in terms of form, planning, materials and construction methods are investigated for various climate categories.

Climate based vernacular building types have not been explicitly nor regularly documented over the past decades, at least not so regularly as it might have been thought. Unfortunately, attempts for linkage of vernacular architecture to climate are often nor systematic or explicit, referring to climate in rather loose terms, following often four basic climate zones: Cold, Temperate, Hot-Arid and Warm-Humid [29], [30]. On the other hand, Rapoport, A., in his elaborated research, investigated vernacular architecture

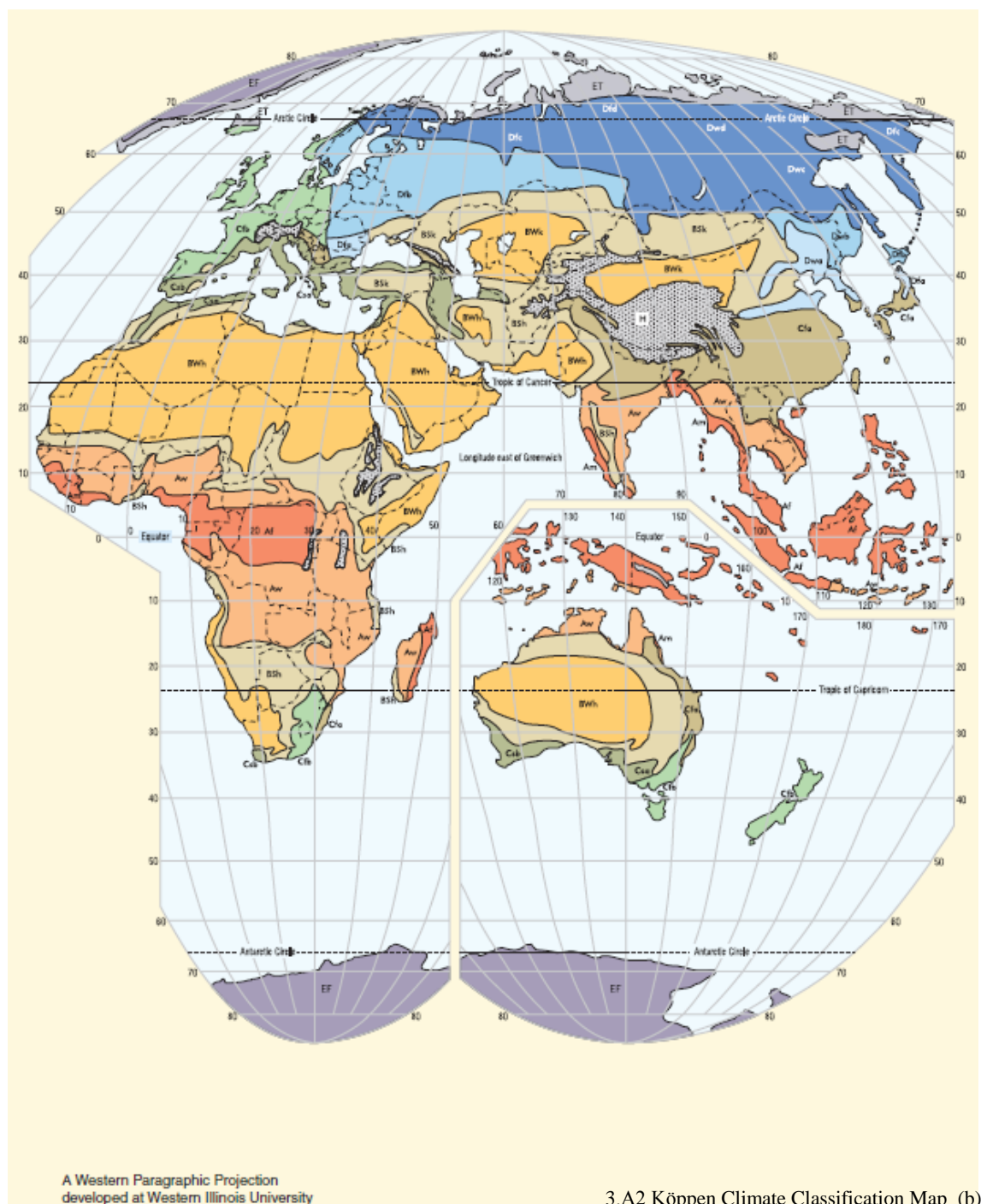
in terms of climatic variables instead of climatic zones, taking into consideration temperature, humidity, wind, rain, radiation and light [8].

For the purpose of this research the systematic linkage of vernacular architecture to particular well- defined climatic zones is attempted. For that reason the most widely climate classification will be used, the simplified Köppen Classification [31]. Vladimir Köppen formulated climate regions so as to coincide with well-defined vegetation regions. This feature enables for the purpose of this thesis to link regional climatic variables to available resources that grow, hence available building materials.

Simplified Köppen Classification. The Köppen system, distinguishes six major climate categories. The first four are based on the annual range of temperatures; humid tropical (A), humid mesothermal (mild winter) (C), humid microthermal (severe winter) (D), and polar (E). The fifth category, the arid climates (B), identifies regions that are characteristically dry based on both temperature and precipitation values, while temperatures range from cold to very hot. Finally, the last category, highland climates (H), identifies mountainous regions where vegetation and climate vary rapidly as a result of changes in elevation and exposure (pic. 3.A1, 3A2) [31].



3.A3-1 Köppen Climate Classification Map (a)



3.2.1 Tropical (A) Climates.

Near the equator we find high temperatures year-round because the noon sun is never far from 90° (directly overhead). Humid climates of this type with no winter season are Köppen's tropical climates. As his boundary for tropical climates, Köppen chose 18°C

(64.4°F) for the average temperature of the coldest month because it closely coincides with the geographic limit of certain tropical palms [31].

Adverse climatic elements

Tropical climates are characterized by moderate temperatures, small diurnal temperature variation, heavy rainfall, high humidity and last but not least intense insolation.

Climate method

The climate requirements call for minimum heat capacity, as excess heat cannot be dissipated due to little diurnal temperature variations. Moreover, maximum ventilation is of prior importance to cope with high humidity, while maximum shading deals with intense insolation and dazzling effects.

Response strategies

Syntax

Siting and planning: The need for maximum ventilation creates long narrow geometry with axis east-west. Forms are spread with wide spacing allowing breezes to enter the interior without barriers.

Relation to ground: The dwelling is often raised above ground not only to permit air circulation from below, but also to protect habitants from flood, insects and animals.

Morphology

Shape: Elongated, open plan is usually preferred in these climates for enhancing maximum cross ventilation. In Africa though, round and rectangular plan is encountered.

Construction

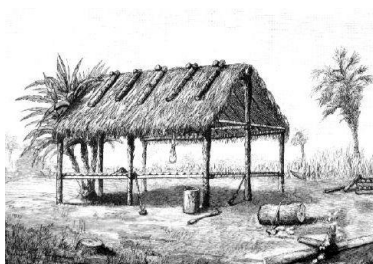
Roof: In these climates, roof is the prevailing element of the house, acting at the same time as a huge, waterproof parasol and umbrella. It is often high-pitched to drain off heavy rains, plus allowing for thermal stratification of hot air, which exerts the house by openings placed on the top of the roof. Deep overhangs cope with heavy rainfalls and intense radiation allowing for ventilation even during rain. Extensive eaves may form porches extending the living space or create cool shady intermediate spaces. In many cases, roof splits in a greater number of smaller roofs, overlapping one another. This reduces the accumulation of heat by allowing air circulation and preventing direct sun radiation. Roof is light-weighted, with minimum of heat capacity to prevent heat storage and reradiation. Moreover, roof permits “breathing” at a certain degree, necessary in

humid climates to avoid condensation inside the strata and the subsequent moisture problems.

Wall: In these climates, the most immaterial solutions are preferred. Walls at minimum, apertures occupying the whole wall face or even no walls ensure the insertion of breezes deep in the house. Walls are light and often permeable to air, made with thatch, wood, bark or bamboo depending on the availability of resources and technology (pic. 3.1-3.12) [32]. In Africa though, earth and wood are the predominant building materials for masonries, used in various techniques such as wattle and daub, adobe and cob. In regions where a change in humidity levels occurs, light structure that contracts on dry season and dilates on wet season can be applied [8]. Nevertheless, opposite solutions can be met, as in Haiti where houses with solid walls and large French doors are common.

Openings: Openings are large and are often covered with dark-colored cane meshes. On the contrary, earth buildings of Africa, present limited openings (pic. 3.14-3.18). It has to be noted though, that in many cultures met at those climates, there is a higher tolerance for acoustic as well as optical privacy, as in Singapore [8]. In cases where optical privacy is of supreme importance, as in Moslem societies, open-work screens have been developed, “protecting” women from public view, while allowing for shading and cross-ventilation at the same time (pic. 3.7) [6].

Floor: Floor is often not only raised but also permeable to air, allowing breezes cooling down the dwelling from below, supplementing the maximum cross ventilation practice (pic. 3.1-3.5, 3.7-3.12).



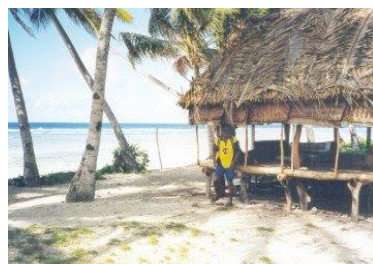
3.1 Seminole Indians house in Florida



3.2 House built with nipa leaves and bamboo in Philippines



3.3 Yagua Indians house in jungle region in Peru



3.4 Palm hut in Ellice Islands



3.5 Thatched hut on tilts in the forest in New Guinea



3.6 Yanomami Indians house in Brazil



3.7 Reconstruction of traditional Malay house in Langkawi, Malaysia



3.8 Replica of Pulau Pinang house, Malaysia



3.9 Replica of traditional Thailand house



3.10 House in Luang Prabang, Laos



3.11 Indian stilt house in Venezuela



3.12 House in rural area of Colombia



3.13 House in Yukata, Mexico



3.14 Earth house in Tallensi, Burkina



3.15 Haya house in Kagera, Tanzania



3.16 Earth house of Kpelle, Liberia



3.17 Wattle and daub house with thatch in Congo



3.18 Rondavel, earth, thatch house in Zambia

3.2.2 Arid (B) Climates

Climates that are dominated by year-round moisture deficiency are called arid climates. These climates will penetrate deep into the continent, interrupting the latitudinal zonation of climates that would otherwise exist. The definition of climatic aridity is that pre-

precipitation received is less than potential ET¹. Aridity does not depend solely on the amount of precipitation received; potential ET rates and temperature must also be taken into account. In a low-latitude climate with relatively high temperatures, the potential ET rate is greater than in a colder, higher-latitude climate. As a result, more rain must fall in the lower latitudes to produce the same effects (on vegetation) that smaller amounts of precipitation produce in areas with lower temperatures and, consequently, lower potential ET rates. Potential ET rates also decrease with altitude, which helps to explain why higher altitude (highland) climates are distinguished separately [31].

Arid climates are concentrated in a zone from about 15°N and S to about 30°N and S latitude along the western coasts, expanding much farther poleward over the heart of each landmass. The correspondence between the arid climates and the belt of subtropical high pressure systems is quite unmistakable (like in the southwestern United States, central Australia, and North Africa), and the poleward expansion is a consequence of remoteness from the oceanic moisture supply [31].

Adverse climatic elements

Arid climates are characterized by large diurnal temperature variation, dryness, intense insolation and last but not least wind-blown sand and dust.

Climate method

The climate requirements call for maximum heat capacity of the building envelope, to utilize diurnal temperature variation for summer cooling and winter heating. Moreover, design opts for minimization of heat gains in summer and heat losses in winter. Ventilation and direct sun radiation is avoided through shading and reduced openings, while the utilization of the small amount of rain can increase humidity levels and provide some comfort by evaporation. Last but not least, sand barriers at openings are vital, while the color of the envelope plays a crucial role for the reflection of the radiant heat.

Response strategies

Syntax

Siting and planning: The need for maximum shading creates compact geometry. Forms are crowded together to enable minimum surface exposed to adverse climatic conditions, and maximum mass to increase the total heat capacity. The crowded volumes, en-

¹ Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the earth's land and ocean surface to the atmosphere.

able not only mutual shading but also breezes to cool down building envelope at night (pic. 3.19-2.23).

Relation to ground: The dwelling is on ground and often sub- or under-terrain. In some cases dwellings are built on cliffs, to take advantage of the stability of earth's temperature, which acts as heat sink, increasing envelope's heat capacity.

Morphology

Shape: Compact plan is usually preferred in these climates for maximizing the volume to the surface area exposed to solar radiation. Moreover, the built weight per unit of volume occupied is increased, hence the thermal inertia of the dwelling is raised.

Plan: Plan breaks down in many rooms. The use of space alters during the day or year according to climatic conditions. Courts and verandahs play a vital role for the micro-climate, offering soothing and cooling psychological effects. Moreover, the wise use of a shady and a sunny court in conjunction, results in a rise of hot air, which travels from the sunny to the shady court through the intermediate rooms. In case where the court is placed high, a projecting "chimney" occurs, producing suction, which encourages cross-ventilation indoors. An exemplar example of this practice can be found in the tall buildings of the Hahramaut in Southern Arabia or in the Moroccan mountains (pic. 3.24). The use of greenery, wells and fountains on the courts increases humidity levels and cools down the air entering the dwelling.

In summer, courts and roofs often facilitate sleeping during evenings or nights, while during day underground spaces offer a comfort refuge. Cooking takes place out of the house for the avoidance of extra heat gains, while it is common to facilitate two kitchens, indoors and outdoors, for winter and summer respectively.

Construction

Roof: Adverse climatic conditions in arid climates are confronted with heavy high heat capacity roofs. Flat, vaulted, beehive or low-pitched roofs are usually met. An exemplar practice is the use of double roofs or even double walls, in which the mud roof is covered by a thatch shield placed over branches and poles, enabling free air space among the two roofs, as noticed in Orissa housing in India (pic. 3.33). In this case, the mud roof is selected clearly for its thermal properties, while the layering of the roof offers many advantages. Firstly, thatch sheds water and protects the mud roof during rain. Moreover, thatch protects the dwelling from the direct sun radiation, hence avoiding adding heat gains. Finally, airspace, mud and thatch layers add insulation and increase roof's heat

capacity. Other examples of double roofs are found on Masa housing in Cameroon, in which two straw roofs are divided by grass separators and on the Bauchi of Nigeria (pic.3.30). The double roof or wall solution is normally found in areas in which their climate is arid for the greater part of the year, but appear also a rainy season, during which their climate resembles that of tropical climates.

Shading, is a priority in design to compensate for intense insolation. Plantation, compact geometry and use of buildings crowded together, verandahs and eaves all contribute to the maximum of shading. In Southern California, the Yokuts shaded even the whole settlement with brushwood [6]–[8].

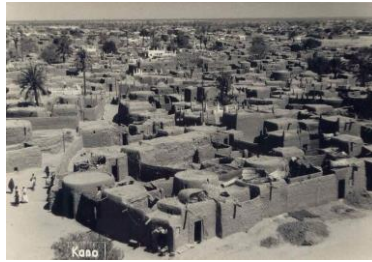
Wall: In these climates, it is crucial to delay the penetration of heat inside the dwelling as long as possible, so that it reaches the interior at night when it is less bothersome. For that reason, heavy, impermeable walls, with high heat capacity are preferred. Walls at maximum, are often painted white color to reflect a maximum of radiant heat (pic. 3.21, 3.28). The use of mud, stone and clay in the form of adobe bricks, is most usual, preferred even if it is structurally unreasonable, (when walls do no bearing, but act only as curtain walls), or even if alternative resources exist. This is dictated primarily for climatic reasons, while the width and the composition of the wall is often regulated according to the climatic requirements, with the insertion of grass to minimize heat capacity for instance.

Openings: Arid climates call for reduced number and size of openings. Apertures are placed high to prevent ground radiation and expel hot air. The covering of openings is related primarily with socio-cultural and religious factors, offering many variants that ensure shading and protection from sand storms. The resident plays a vital role for the sufficient climatic performance of the dwelling. Windows are ideally totally closed during daytime, when sun is high and temperature raised, keeping off hot spells and sun radiation. At night though, they are fully opened to allow cool breezes enter the interior and cool the dwelling, taking advantage of the cooling effect of nocturnal ventilation.

Floor: In arid climates, preservation of water is vital for the survival of man. In many cases, water is retained and protected from evaporation, by storing it in underground tanks under the dwelling. This practice increases the thermal inertia of the house, while at the same time cools the floor through the small evaporation of the water.



3.19 Er-Rachidia, Morocco



3.20 Kano , Northern Nigeria



3.21 Tufa pinnacles in Cappadocia,



3.22 Earth houses in Syria



3.23 Touggourt, Algeria



3.24 Earth house in Wadi hadhramaut, Southern Yemen



3.25 House of Welayta tribe , Ethiopia



3.26 Rubble stone house bonded with mud plaster in Lalibela, Ethiopia



3.27 Beehive house of adobe blocks, coated with clay in Syria



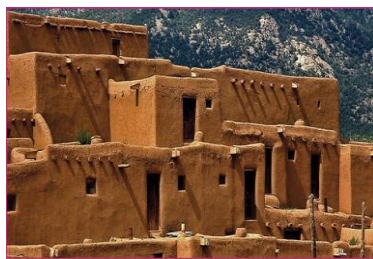
3.28 Earth house in Egypt



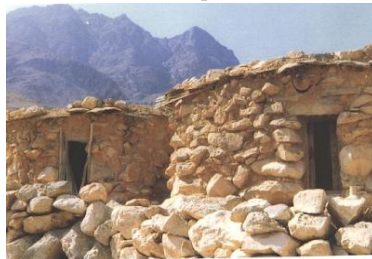
3.29 House of mud, reinforced at intervals with poles in Botswana



3.30 Earth house with double thatch roof in Bauchi, Nigeria



3.31 Taos Pueblo, adobe houses in New Mexico



3.32 Stone houses in UAE



3.33 Earth house with thatch double roof in Orissa, India



3.34 Navajo hogan, wattle and daub house in Arizona, USA



3.35 Earth house in Kenya



3.36 Adobe house in Chad



3.37 Earth house in Afghanistan



3.38 Desert thar, earth house in Rajasthan, India



3.39 Earth house of Hopi Indians in Arizona, USA

3.2.3 Polar (E) Climates and Microthermal (D) Climates

Just as the tropical climates lack winters (cold periods), the polar climates—at least statistically—lack summers. Polar climates, as defined by Köppen, are areas in which no month has an average temperature exceeding 10°C (50°F). Poleward of this temperature boundary, trees cannot survive. The 10°C isotherm for the warmest month more or less coincides with the Arctic Circle, poleward of which the sun does not rise above the horizon in midwinter and though the length of day increases during polar summers, the insolation strikes at a low angle [31].

Except where arid climates intervene, the lands between the tropical and polar climates are occupied by the transitional middle-latitude mesothermal and microthermal climates. As they are neither tropical nor polar, the mild and severe winter climates must have at least 1 month averaging below 18°C (64.4°F) and 1 month averaging above 10°C (50°F). Although both middle-latitude climate categories, microthermal and mesothermal, have distinct temperature seasons, the microthermal climates have severe winters with at least 1 month averaging below freezing. Once again, vegetation reflects the climatic differences. In the severe-winter climates, all broadleaf and even some species of needle-leaf trees defoliate naturally during the winter (generally, needle-leaf trees do not defoliate in winter) because soil water is temporarily frozen and unavailable. Much of the natural vegetation of the mild-winter mesothermal climates retains its foliage throughout the year because liquid water is always present in the soil. The line separating mild from severe winters usually lies in the vicinity of the 40th parallel [31].

Man marginally survives in polar climates, while the most known tribe at those regions, Eskimos, used territories lying north of the 12°C August isotherm, which defines the northernmost limits of the tree-line and the territories of the forest Amer-Indians [27]. This means that their territories intervene in both polar and microthermal climates.

For the purpose of this study, polar and microthermal climates will be treated together as far as climatic control methods are perceived, since in both cases low temperatures is the prevailing challenge for survival.

Adverse climatic elements

Polar and microthermal climates are characterized by extremely low temperatures, low insolation and often strong winds.

Climate method

The climate requirements call for maximum heat capacity of the building envelope, to prevent the loss of heat to the outside. Moreover, design opts for maximization of heat gains taking advantage of solar radiation, with the use of dark colors. Ventilation is avoided, while envelope should be impermeable to prevent air leaks and breezes.

Response strategies

Syntax

Siting and planning: The need for maximum protection against severe cold and wind creates compact geometry. Although, this syntax eliminates cold breezes, this is achieved at expense of solar radiation. Forms are often crowded together to enable minimum surface exposed to adverse climatic conditions, and maximum mass to increase the total heat capacity (pic. 3.46, 3.48). The same strategy applies in arid climates, in which the climatic goal is the same; the prevention of heat transfer. What changes is just the direction of heat flow.

Adverse syntax is met too, dictated by socio-cultural factors. Houses of Eskimos were built dispersed along the extended marginally populated territories, accommodating one family. Nevertheless, in case when two or more families wished to link up during harsh winter period or when storage room was in need, a domical shell would be added in the existing dwelling.

As far as siting is considered, the most sheltered spots are preferred, often hillsides that face the sun, or in the lee of raised cliffs in order to avoid cold breezes and take advantage of solar radiation. Igloos for example are often encountered in the back of a cliff facing the beach [27].

Relation to ground: The dwelling is on ground and often subterranean or semi-subterranean to avoid winds and take advantage of earth's higher temperature.

Morphology

Shape: Compact volumetry is usually preferred in these climates for maximizing the volume to the surface area exposed to adverse climatic conditions. Moreover, the built weight per unit of volume occupied is increased, hence the heating capacity of the dwelling is raised.

Plan: Compact plan is also preferred. As external heat gains are minimal, internal heat gains are crucial. For that reason, stove elements and kitchen are usually found in the center of the house to heat up the dwelling. Moreover, latent heat by people and animals is taken of advantage. In many cases, cattle is even kept inside the house, to heat up the dwelling and make easier the feeding and caring of animals without having to walk/be exposed to cold. For the same reason, storage rooms and secondary spaces are placed north to offer a heat barrier to extreme cold.

Construction

Roof: Adverse climatic conditions in polar and microthermal climates are confronted with heavy high heat capacity roofs. Flat, vaulted or low-pitched roofs are usually met. Snow is often encouraged to build up in thick layers over roof, for its insulating properties. This practice affects the form, size and structure of roofs in order to carry the extra loads. In tundra and sub-arctic regions vernacular roofs are most commonly made from large wood timbers covered with turf as in Glaumbær, Iceland (pic.3.46) [32].

Wall: In these climates, it is crucial to prevent the penetration of heat outside the dwelling. Different layers of materials are often used, focusing on increasing envelope's heat capacity and wind proofing. For that reason, heavy impermeable materials are usually preferred, used in a wise combination to make envelope windproof and heavy. Snow, stone, wood, sod and turf are often encountered, in various combinations. The same solution, of multiple layering is followed even if it is structurally unreasonable, dictated primarily by the need to confront adverse climatic conditions. The Siberian house of Yakut for example, uses a timber skeleton, covered with wood and a heavy layer of sod to reach the desired level of insulation (pic. 3.47). Similar practice can be encountered in Alaska, in cases where driftwood could be obtained. Eskimos built log houses packed over with sod, rectilinear in plan.

In addition, a common practice, especially among Eskimos, is the doubled-skinned dwelling. A tent from hides lines the envelope, acting as additional insulation, securing that a volume of cold air could be trapped within the hides and the internal surface of

the snow-blocks. This prevents the snow shell from melting, acting as adding insulating layer in the envelope's construction.

Openings: Irrational as it might seem to current technology, microthermal and polar climates call for reduced number and size of windows (pic. 3.42-3.52). Solar radiation as valuable as it might be for these climates could not be taken advantage of, as glass openings could not be supported by the available technology. Apertures are often covered with skins.

Floor: Floor is often raised and entrance is wisely designed to minimize heat losses. Eskimos used a narrow entrance passage, formed as tunnel, often at a lower level than that of the internal floor level, in order to prevent cold air from entering the shell. Entrance passage was even subterranean or angled. At the same frame, smaller entrance was also used in Korean peninsula, in Suwon, where vernacular houses utilized an underfloor heating system to keep the interior warm, the *Ondol* (pic. 3.40).



3.40 Wood and clay house of Sami people in Rovaniemi, Finland



3.41 Pertinotsa farmhouse in Karelia, east Finland



3.42 Barabara, sod and grass roof layered over a frame of wood or whalebone in Aleutian chain Islands



3.43 House with underfloor heating (Ondol) in Suwon, Korea



3.44 Snow house in Baffin Island, Canada



3.45 Norse sod longhouse in Newfoundland and Labrador, Canada



3.46 Turf houses of the burstabær style in Glaumbær, Iceland



3.47 Wood and sod houses of Yakut in Verkhoyansk, Russia



3.48 Log cabin fishermen huts in Altja, Estonia



3.49 Kwiakiutl house, Northwest Pacific, Canada



3.50 Earth house of Pawnee Indians in Nebraska, USA



3-51 Wood and mud house in Lviv, Ukraine



3.52 Timber house near Volga, Russia



3.53 Wood and mud house in Kursk, Russia



3.54 Timber house in Russia

3.2.4 Mesothermal (C) Climates

Adverse climatic elements

Mesothermal climates feature no extreme temperature and precipitation levels for prolonged periods. On the opposite side, variable climatic conditions are alternated throughout the day and year. Mesothermal climates are characterized by mild cold winter, hot summer and two transitional periods, autumn and spring, during which transition from one extreme to another occurs. This alteration of climate challenges design, making one strict solution unsuitable.

Climate method

The climate requirements call for flexibility in design in order to correspond to variable climatic conditions. Maximum heat capacity of the building envelope, to utilize diurnal temperature variation for summer cooling and winter heating is desirable. Moreover, design opts for minimization of heat gains in summer and heat losses in winter. Direct sun radiation is handled wisely, allowing solar access in winter and minimizing insolation in summer, using well designed overhangs and eaves. Ventilation is utilized in summer for cooling down the envelope, by placing appropriate openings that encourage cross ventilation.

Response strategies

The principle answer to this climatic type is flexibility. Architectural solutions found on these climates are more or less encountered in extreme climates as described above, enriched with flexible systems to anticipate for the complexity of weather challenges.

Regulation of openings, shading systems and insulation is of supreme importance. This necessitates the active participation of the habitant for the efficient climatic energy performance of the building.

Syntax

Siting and planning: In mesothermal climates lacking extremes, neither compact nor loose syntax is encountered. This syntax, enhances the access of solar radiation to the volumes on winter, while enabling breezes cool down building envelope on summer. Vegetation is of prior importance, affects and enhances dwelling's planning.

Relation to ground: The dwelling is on ground, as environmental conditions are mild.

Morphology

Plan: Intermediate spaces between indoors and outdoors are incorporated in the design, operating as filters to the innermost of the house. The use of space usually alters during the year or day according to climatic conditions. Court, porches and verandahs play a vital role for the microclimate, offering soothing and cooling psychological effects.

Construction

Roof: A certain pattern for roofs cannot be spotted. Low as well as high pitched, flat and vaulted roofs are encountered depending on local precipitation levels and material's properties.

Wall: In these climates, middle to high thermal mass walls are encountered to keep interior temperatures at a comfort level. Earth, stone and wood are preferred, used in various widths according to thermal mass and insulation requirements. Walls at maximum, are often painted white color to reflect a maximum of radiant heat (pic. 3.55-3.57, 3.58, 3.66).

Openings: Apertures are fully regulated by controlling the openness, shading and insulation of the windows. More specifically, mobile shading systems, such as louvers, enable the desirable proportion of solar radiation to penetrate the interior. Shutters and curtains often work as adding mobile insulation, used to exclude solar radiation on summer

days, minimize heat losses during winter and regulate ventilation (pic. 3.55, 3.58, 3.59, 3.65, 3.65).

Awnings and eaves are wisely designed to enable low winter sun to enter the interior and at the same time exclude solar radiation on summer when sun is high. On the same frame, plantation supplements the selective shading practice, with the use of deciduous trees. Lavishly plants, often revolved over arbors, protect openings and building envelope from direct solar radiation on summer, while on winter shed their foliage for maximum insolation (pic. 3.56, 3.57).



3.55 Farmhouse in Ibiza, Spain



3.56 Whitewashed schist houses in Paros, Greece



3.57 Trulli made of limestone and keystone, Alberobello, Italy



3.58 Wood and stone houses with thatched roofs in Santana, Portugal



3.59 Stone farmhouse in Périgord, France



3.60 Thatched cottage in Sligo, Ireland



3.61 Stone houses of Miao tribe in Guizhou, China



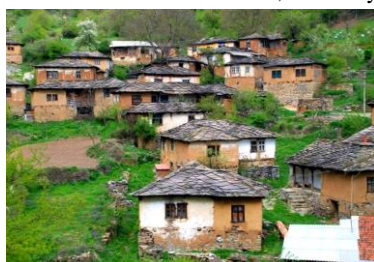
3.62 Wooden frame and brick houses in Rheinland-Pfalz, Germany



3.63 House from limestone in Cotswolds, England



3.64 Stone houses in Dachang, China



3.65 Stone house in Gostuša, Serbia



3.66 Wood and clay house in Komlóská, Hungary

3.2.5 Highland (H) Climates

The pattern of climates and extent of aridity are affected by irregularities in Earth's surface, such as the presence of deep gulfs, interior seas, or significant highlands. Highlands can channel air mass movements and create abrupt climatic divides. Their own microclimates form an intricate pattern related to elevation, cloud cover, and exposure. These areas often have cold winters and mild summers. Due to their elevation, temperatures are lower than expected in such latitude, while the main form of precipitation is snow, often accompanied by strong winds. Moreover, one significant effect of highlands aligned at right angles to the prevailing wind direction is the creation of arid regions extending tens to hundreds of kilometers leeward [31].

Highland climates can be found in the high land and mountainous areas of the world, such as the Cascades, Sierra Nevada and Rocky Mountains of North America, the Andes of South America, the Himalayas and adjacent range and the Plateau of Tibet of Asia, the eastern highlands of Africa, and the central portion of Borneo and New Guinea. In fact, highland climates are not usually preferred for habitation and respective examples of vernacular architecture are hard to find.

Adverse climatic elements

Climatic challenges on highland regions vary depending on nearby lowland climate, exposure, elevation and angle of the settlement to the prevailing wind. Annual ranges in temperature are decreased, while diurnal ranges are increased. Prevailing winds are the most crucial climatic element in this case, exaggerating the existing climatic conditions. More specifically, in case where highlands intervene in arid or microthermal climates, dry or cold wind respectively, becomes undesirable.

Climate method

The climate requirements call for maximum heat capacity of the building envelope, to prevent the loss or gain of heat in extremely cold or hot and arid climates respectively and to compensate for the large diurnal ranges. The sitting and syntax of dwellings, as well as volumetry are of supreme importance to cope with steep inclination, harsh winds and low temperatures. Building's envelope is wisely treated to prevent air leaks and breezes.

Response strategies

Syntax

Siting and planning: The need for protection against severe winds creates compact geometry, harmonically sited in the inclined terrain. Forms are closely packed to enable minimum surface exposed to adverse climatic conditions. The crowded volumes, lower windspeed and discourage generation of tornados in public space, by forming narrow paths between the dwellings.

In cold climates, slopes facing south are usually preferred to keep north face protected from cold winds.

Relation to ground: The dwelling is often half sunk into the ground or even under-terranean to escape wind. In cases where low temperatures prevail, the adaptation of the dwelling on inclination is such that north wall is one story high and south wall two stories high (pic. 3.67-3.69).

Morphology

Shape: Compact plan is usually preferred in these climates for maximizing the volume to the surface area exposed to adverse climatic elements. Square and rectangular plan is encountered.

Plan: Plan often combines the function of living room, bedroom and kitchen with an open hearth in an integrated space. Since land available for construction is valuable, dwelling develops in more than one stories. In two stories houses, ground floor serves as stable or store room, while the second floor serves as living quarter, as in castle-like houses of Tibet, or alpine house of Valais in Switzerland [27], [33]. In other cases, the use of space alters during the year according to climatic conditions. In Tibetan cave dwellings as well as castle-like houses, second floor is used in summer, while ground floor facilitates living in winter for it is warmer (pic. 3.72) [33].

Construction

Roof: Adverse climatic conditions in Highland climates are confronted with heavy high heat capacity roofs, made by stone. Flat, low-pitched roofs are usually met dictated by the properties of available resources as well as the severity of winds.

Wall: In these climates heavy, impermeable walls, with high heat capacity are preferred. The use of stone, wood and earth is most usual, while the width and the composition of wall is dictated by climatic conditions and material's properties. Stone walls are usually

plastered with mud to achieve impermeability. In many cases, the material and composition of wall alters at height. A typical example is the use of stone for the base of the house and the use of timbers for the superstructure, as in Nuristan of Afghanistan (pic. 3.68) [27].

A specific element, presented in such climates is the windpole, adapted in the façade of the dwelling that suffers from winds the most. A group of windpoles planted in front of the house was once very common in Switzerland [8]. At the same frame, vertical posts grounded on earth at Nuristan, protect the house not only against the force of the wind but also against the threat of earthquakes. Protection against wind, is also offered by the planting of windbreaks in front of and around houses, with the roots of trees enhancing the stability of soil and prevent ground erosion from heavy rains.

Openings: Highland climates don't exhibit a specific pattern for openings. In two story houses sunk into the ground, north wall is often either blank or with very few openings, while the wall facing south has more windows protected by shutters, as in the mountainous region of Provence [8]. Openings placed in succession, occupying an extending portion of wall facade are also encountered, as in Törbel of Switzerland or Nuristan of Afghanistan (pic. 3.67, 3.68). On the other hand, stone houses often present marginally no windows, with tiny apertures intervening in the construction offering ease and flexibility in handling (pic. 3.70).



3.67 Törbel, Switzerland



3.68 Timber and stone houses in Nuristan, Afghanistan



3.69 Wooden chalets in Hallstatt, Austria



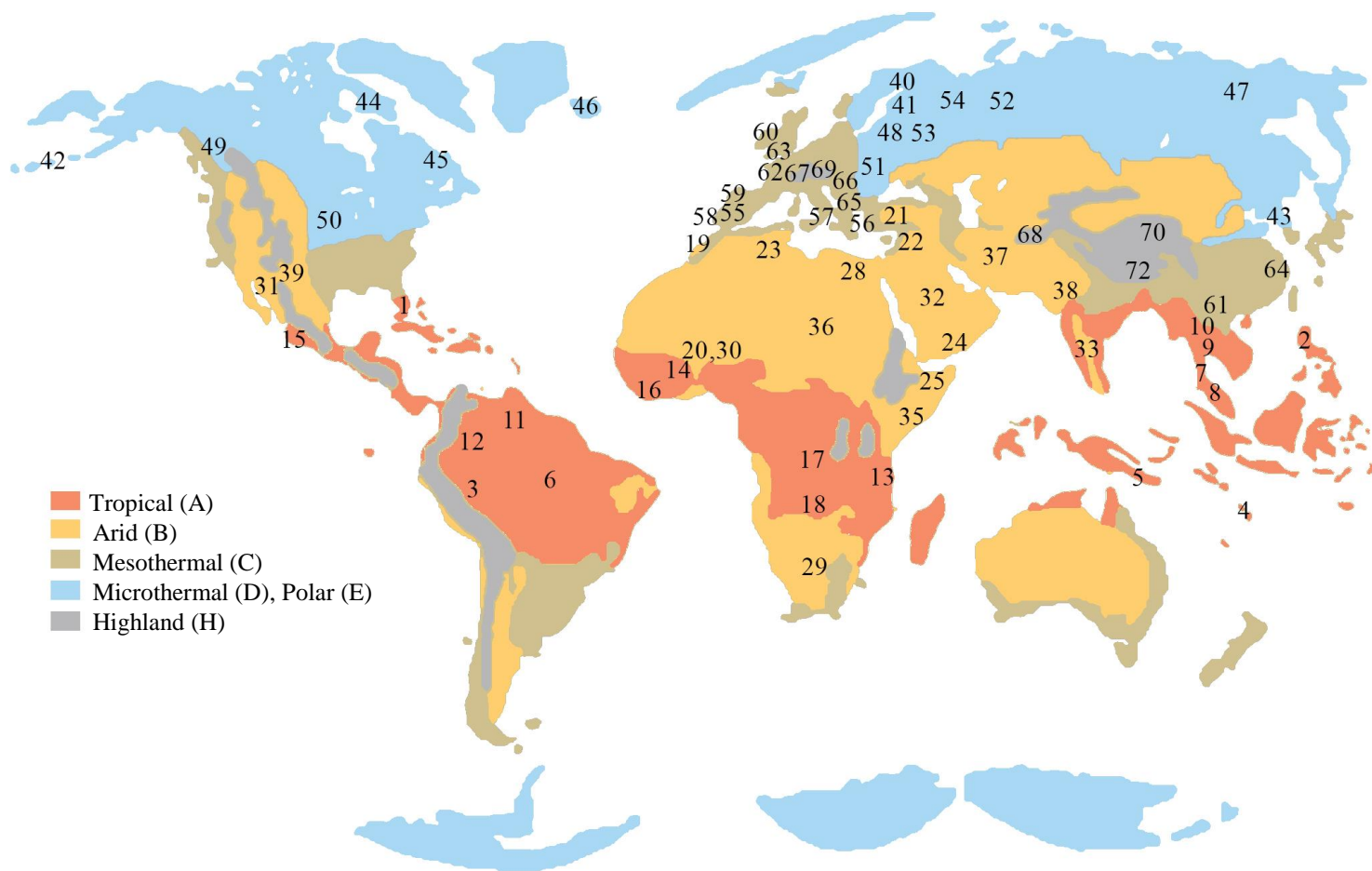
3.70 Stone house in Suoxian, China



3.71 Wooden chalets and narrow streets in Törbel, Switzerland



3.72 Castle-like house made with stone, earth and wood in Lhasa, China



3.73 Indicative examples of vernacular architecture (Indexes refer to photographs)

Syntax Siting and planning	Relation to ground	Morphology Plan / Shape	Construction Roof	Wall	Openings	Floor / Systems
Tropical						
Arid						
Polar/ Microthermal						
Mesothermal						
Highlands						

4 Vernacular architecture in contemporary building design_ modern earth architecture

Vernacular occurs, happens and afterwards it is recognized, appreciated and recorded as such. Vernacular presupposes tradition. It is the oral/ written transfer of designing and building tradition passing from generation to generation, from teacher to apprentice that vitalizes the “vernacular”.

In vernacular architecture building forms and techniques are embraced and expressed by the whole community. Building experts and owners share the same design and building language and contribute in the design and building process in collaboration.

In that sense, in regions where vernacular building tradition has given its place to industrialized building techniques and contemporary building forms, an effort to impose old vernacular forms and techniques would be irrational. Even if such an imposition was applicable, the social, economic and cultural viability and appropriateness of such an architecture would be of question.

Hence, since the scenario of the absolute application/ revival of vernacular forms and techniques is out of question, we could try to embody the rationale behind vernacular building forms and techniques to serve contemporary design standards and expectations. In that frame, worldwide practice is examined to find examples in which techniques of vernacular architecture have been enhanced and integrated in contemporary building design.

4.1 Method of study

Worldwide practice will be investigated using as chariot the current use of traditional building materials and techniques. In that frame, the research focuses on earth architecture, through its two predominant techniques; adobe and rammed earth [34]. Earth architecture can be a sound basis for the investigation of vernacular techniques applied in contemporary context due to its popularity. According to Varum et al. 30% of world population dwells in earth buildings [35].

Firstly, a definition of modern earth architecture is attempted. Proceeding, a thorough analysis of adobe and rammed earth techniques is conducted, taking into account mate-

rial's properties, cost, availability and recent developments in the field. In the end of this chapter, code provisions for earth building with a focus on rammed earth and adobe are investigated.

4.1.1 Modern earth architecture

Modern earth architecture refers to a building where a significant part of the envelope and/or structure comprises graded soil applied with one or more of raw earth techniques (e.g. rammed earth, adobe, cob). However, the specification of modernity implies four factors;

1. The applied earth techniques benefit from state of the art innovation and developments on the field.
2. A high quality of construction is met, regarding dimensional tolerances, accuracy, and compatibility with required mechanical and electrical equipment.
3. A high level of indoor comfort conditions is achieved, alongside with low environmental impacts taking into consideration operational energy costs and embodied energy.
4. Compliance with national guidelines and codes is fulfilled [36].

4.1.2 Adobe



4.1 Earth mixture placed into moulds

Adobe bricks are rectangular prisms made of earth mixed with water and organic material, such as straw, dung or plant juices. After drying on sun, bricks can be assembled with the application of adobe mud that bonds them into a structure. Adobe building offers optimal

thermal-mass storage, heat-transmissive properties and sound- transmission levels. As manufacturing of firm adobes requires appropriate drying on sun, arid climates have been traditionally linked to this construction technique [37]. Production of adobe can be local and decentralized, which keeps costs low. In addition, it is nontoxic, while according to Gernot Minke, producing adobe blocks takes only 1% of the energy required to produce fired bricks or Portland cement [38].

Adobe construction process is considered relatively fast, compared with other earth building techniques as cob or rammed earth. Although adobe may be labor-intensive, it

can boost local economies, where work forces with limited opportunities are in abundance.

History

In the history of human settlement, adobe mud plasters along with wattle and clay earth daub may be the first human made building materials. The oldest exhibit of adobe building is located in Jericho, dating from 8.300 BC [39]. Adobes are common in the Middle East, North Africa, America, and parts of Europe, especially Spain. By 4.000 years ago, Egyptians and Babylonians used mud brick for the construction of pyramids and ziggurat respectively [27].

Puebloans, a tribe of Native Americans in the Southwestern United States worked with mud bricks to construct their pueblo apartments, until the Spaniards entered the era in the 16th century. In Yemen, top floor walls of the 4- to 8-story houses were constructed with adobes dating at 1.000 BC [40].

Adobes have no standard size, with substantial variations at dimension, weight and composition developed over the centuries and in different geographical regions.

Characteristics

Structural capability

Adobe is suitable for low rise structures. It can be used though for multistory loadbearing structures, only when applied with enough thickness. As has been already mentioned, even 8-story houses have been constructed in Yemen, yet typically adobe is used in single or double story structures [41]. Moreover, it offers a simple structural solution for more sophisticated forms, such as vaults, arches or domes, which cannot be constructed by other raw earth techniques, such as rammed earth.

Thermal mass

According to Baggs and Mortensen, adobe has 1300 KJ/m³.k volumetric heat capacity, resembling brick [42]. In order to provide effective thermal mass, adobe walls should be constructed in enough appropriate thickness.

In an earlier study, Baggs et al. conclude that an adobe wall of 0.25m will provide a thermal lag of 9.2 hours [43], while Fgaier et al. in their recent study on thermal performance of three types of adobe suggest that the ideal thickness for adobe to ensure the greatest heat capacity and a thermal lag between 10 and 12 hours is between 0.3 and 0.4m. [44]

Insulation

Since, adobes are extremely dense, molecules of air cannot be trapped within the structure to offer bulk insulation. In milder climatic regions, adobe walls might not need added insulation but that's not the norm.

In vernacular architecture, earth buildings feature walls up to a meter thick. In that way, sufficient insulation and enormous thermal mass is achieved, but at expense of valuable useful area, a sacrifice not suitable for contemporary building practice.

Moisture resistance

Although some soils are very resistant to weathering, adobe is susceptible to moisture penetration. Exposure to extensive moisture and driving rain can prove detrimental for adobe constructions, thus sufficient roofing with deep eaves and appropriate foundation is necessary, a practice carefully applied in vernacular architecture. Contemporary research and practice focuses on the use of plasters and stabilization additives to improve adobe's impermeability to water (More details on *Contemporary use*).

Environmental impacts

Adobes have potentially very low environmental impact, with even the lowest embodied energy of all building materials [41]. However, the use of highly processed additives, such as asphalt or cement, extensive mechanization and transportation increase the “delivered” embodied energy of adobe, similarly to other earth construction techniques.

In order to keep greenhouse gas emissions to possible minimum, use of on-site/short-logical distance materials, avoidance of highly processed additives and low mechanization is required. It is noteworthy that, a stabilized adobe wall of 300mm with 5% cement, is a fairly high energy building material, resembling a 125mm unreinforced concrete wall [41].

Buildability, availability and cost

Adobe is a material easy to work with, well suited to owner-builder system. However, unless owner is involved in construction process or cheap workforce is available, adobe is an expensive solution according to Australian guide for environmentally sustainable homes. Moreover, commercially produced adobes can be at the same or even higher cost than brick veneer [41].

Contemporary use

Unfortunately, utilization of adobes is hindered by their poor mechanical properties, regarding mainly their bad performance against humidity. In more detail, although the dried compressive strength of adobe can reach 4 MPa, its wet compressive strength is near zero [45], [46]. This means that, buildings in which adobes are exposed to rain, are eroded after each rainy season, requiring annual maintenance, in expense of money and time. In order to improve adobe's impermeability to water two methods can be applied; application of plasters and stabilization [47].

In early 1930s, Oklahoma State University researched the stabilization of adobe with asphalt emulsion. As soon as by mid-1930s, large-scale mechanized production of adobes stabilized with asphalt had begun in California [40].

Fifty years later, in 1981, Richard Ferm wrote a manual for stabilized earth construction, entitled *Stabilized Earth Construction: An Instruction Manual*. The specific manual focused among others on the right use of emulsified asphalt in order to stabilize soils for adobe construction.

Later on, many researches for the stabilization of adobe have been conducted, investigating the optimal addition of cement [48] and even the addition of by-products [49] and vegetable materials [50]–[52], such as bamboo particles [53]. In more detail, as far as cement stabilized adobes are concerned, Dao et al. on their recent study on thermal, hydric and mechanical behaviors of cement stabilized adobes, concluded that adobes stabilized with 2wt% of cement can be a suitable building material for mass housing in Burkina Faso [48]. The research took into account compressive strength, moisture resistance, thermal conductivity and economic cost.

The stabilization of adobe with asphalt emulsion offers many advantages according to Ferm, R. First and foremost, when fully stabilized, adobe gains greater resistance to water penetration and erosion, hence retaining its strength in wet conditions. Furthermore, this waterproofing increases its long-term durability by reducing swelling and shrinking, thus reduces maintenance costs too. Finally, emulsified asphalt adobe walls are more durable against exterior water and wind erosion, while are proofed against animal, insects and fire [54].

In the United States, adobe traditions are still alive, especially in New Mexico and Arizona, heavily influenced by Pueblos and Spanish. According to Minke, G. there are approximately 75.000 homes built of adobe or rammed earth in New Mexico, while

adobe is commercially mass produced in New Mexico, Arizona and California with aid of machinery [38]. Dimension, as well as percentage of asphalt and cement emulsion, varies according to the need for protection against moisture damage and earthquake threaten.

As with all earth building techniques, adobe is treated with skepticism and prejudice. It is quite encouraging though, that a swift in the clientele of adobe building owners has occurred. More specifically, most of the adobe homes now being built in USA, refer to high salary byers with high quality and comfort standards [40]. This swift contributes to alleviate the misconception and prejudice that adobe is accompanied with poverty or poor performance.

Table 1

Time lag and thermal mass values for predominant building materials according to Baggs et al. 1991 and Baggs and Mortensen 2006

Material thickness (mm)	Time lag (hours)	Thermal mass (volumetric heat capacity, KJ/m ³ .k)
Double brick (220)	6.2	1360
Concrete (250)	6.9	2060
Autoclaved aerated concrete (200)	7.0	550
Earth wall/ Adobe (250)	9.2	1300
Rammed earth (250)	10.3	1673
Compressed earth blocks (250)	10.5	1740

4.1.3 Rammed earth



4.2 Tamping of rammed earth

Rammed earth building utilizes bulk materials found on site. These are compacted into form work that is set directly on a foundation, usually made of stone or concrete. Its main advantages, shared by most earth materials are that in its traditional technique it is regional, unprocessed, low-cost, heat storing, absolutely recyclable, with exemplar interior comfort level and quality, as well as thermal and acoustic superiority. Earth walls, properly designed and constructed, can reduce the use of construction materials, as well as the construction waste, while conserving energy in the operation cycle of the building [55].

History

The origins of rammed earth are not well documented. Nevertheless, archaeological evidences on different sites around the world show that the technique of packing moist soil into form work was used as early as seventh millennium BC. Chinese knew rammed earth technique for more than 3.000 years, while Romans brought it to Europe. Indicatively, part of the Great Wall of China and even all early civilizations in Near East are constructed among others from rammed earth [27].

Building with rammed earth was never completely vanished in many parts of the world. In fact, in regions where access to mechanization is economically out of question, the traditional method of rammed earth is still alive.

In France, during the latter part of the eighteenth century, a builder called Francois Cointeraux fascinated by the technique of rammed earth published several manuals, which in turn prompted the publication of numerous articles in Europe, England and USA [56]. Moreover, rammed earth was prolonged used in Europe during the post three centuries, evidenced by a 1970's survey, conducted by the College of Architecture of Grenoble (EAG). The survey revealed that thousands of rammed earth houses and barns were constructed around the Rhone region, some as old as 400 years, advocating that when constructed properly rammed earth buildings can outperform even stone.

Characteristics

Structural capability

History has shown that traditional rammed earth can be suitable for low rise structures with satisfactory durability. However, stringent durability criteria required by contemporary standards necessitate soil stabilization[57]. As noted by Arrigoni et al. unstabilized rammed earth fails strength and durability criteria [58]. When stabilized though, its mechanical properties are enhanced, while multistory loadbearing construction can be achieved as in Queensland/Australia, where a five-story hotel is built by stabilized rammed earth. Moreover, reasonably high strengths can be achieved with appropriate engineering, while reinforcement is possible in a similar way to concrete.

Thermal mass

According to Baggs and Mortensen, rammed earth has $1673 \text{ KJ/m}^3\cdot\text{k}$ volumetric heat capacity, resembling a heavy weight masonry with high thermal mass [42]. This feature,

enables the storing and release of heat during the day, optimum for climates with large diurnal ranges.

When applied correctly and in the right climate, the thermal mass can delay the penetration of heat through the building envelope by 10.3 hours [43]. In that way, diurnal temperature variations can be exploited and equilibrated.

High thermal mass of rammed earth is optimum for climates with at least 6°C difference between day and night outdoor temperatures [59]. In climates though, with lower variation, such as tropical climates, high thermal mass can cause great thermal discomfort by holding too much heat.

Rammed earth apart from external loadbearing masonry can be also applied as a feature wall within a well-insulated envelope incorporated in microthermal, polar and arid climates. In that way, the internal rammed earth wall simulates a battery of useful thermal storage.

Insulation

Unfortunately, rammed earth wall has limited thermal insulating qualities- resembling an uninsulated fibre cement wall [59]. Insulation can be added with linings in the inner part of the wall, but this system fails to meet building code requirements for insulation, as Building Code of Australia. The placement of insulation on the outside part of the rammed earth masonry is also possible and fully exploits the wall's thermal mass. However, it holds a main drawback; the loss of the desirable look, texture and aesthetics of the façade of the building.

A compromising solution, for external rammed earth walls is the placement of insulation within the thickness of the wall. This system comprises, sufficient insulation and high aesthetics in both parts of the masonry, yet it comes with an adding cost and a change in wall's structural properties. Many companies especially in US and Canada hold such technology for structural insulated rammed earth walls.

Moisture resistance

Rammed earth walls are porous and need protection from driving rain and extensive moisture exposure. An efficient foundation and roofing system is necessary for the protection of the tops and bottoms of the masonry.

New water repellent additives launched by rammed earth construction companies in US, Canada and Australia can waterproof walls right through. However, it has to be noted that such additives may inhibit material's breathability.

Environmental impacts

Rammed earth is not a priori a superior green material, since its environmental impacts depend on stabilizing additives (the most prominent; cement), degree of local material sourcing and manufacturing process. In more detail, although in principle rammed earth as other earth techniques is a low greenhouse gas emission product, transportation, excessive use of highly processed additives and manufacturing process can surpass this advantage. For example, according to Australian's guide for environmentally sustainable homes, a 300mm rammed earth wall with 5% cement content has the equivalent of 150mm thickness of cement wall and equivalent of more than a 100mm concrete wall.

Venkatarama and Prasanna though, researched the embodied energy of cement stabilized rammed earth (CSRE). They concluded that embodied energy of CSRE walls increases linearly with the increase in cement content. It is noteworthy though, that CSRE walls with 8% cement content feature only 15-25% of the embodied energy of burnt clay brick masonry [55].

Arrigoni et al. in their recent study, focusing on environmental impacts and durability of stabilized rammed earth, concluded that although cement stabilized rammed earth features the highest unconfined compressive strength, it comes with the highest environmental cost. However, durable stabilized rammed earth is possible by using environmentally friendly additives such as waste products. It was found that, when soil available on site is not suitable for construction, the environmental impacts of unstabilized and stabilized with waste products mixes are similar [58].

Buildability, availability and cost

Rammed earth cost can vary according to the use of local source material, the complexity of the design, the local network of building experts, the availability of formwork in the area and the inclusion of engineers in the project. In cases, where rammed earth is well established in an area, it can be an economical and safe option. Otherwise, in places where it is considered a rare construction material, its specialist nature and absence of experienced builders are reflected in its higher cost [59].

Yet, a determining factor for the cost of rammed earth is its construction time. Even with the use of tractors and air compressors, rammed earth is still a relatively slow con-

struction process. Taking into account that rammed earth walls for a single-family residence can take up to three weeks to build, the process cannot compete with the price demands exerted by conventional building practices, such as frame and stucco [56].

However, when designing simple walls with no complexity and use human power for ramming and simple wooden formwork, traditional rammed earth technique can be low cost and energy.

Contemporary use

Nowadays organizations promoting earth building have been spread throughout the world, conducting a great number of workshops that include training upon a rammed earth project. One of the most known, the French CRA Terre organization, was founded in 1979 and linked to the School of Architecture of Grenoble. It conducts training programs that have resulted in successful construction projects on the village scale in Africa, Asia and South America. Houben et al., mentions that indicative of CRA Terre's extended educational role is the fact that an educational program has been attended by 11.000 visitors in just 4 years [60].

In the early 1970's, in France, Australia and US, a revival of interest for rammed earth construction in new, more sophisticated projects began. Also, in California, Arizona and New Mexico, an increasingly appreciative clientele espoused rammed earth techniques. Most importantly, in Western Australia, an unprecedented blooming of rammed earth construction took place, when a ravenous termite population precluded the use of wood walls in any forms. Under these circumstances, once rammed earth was launched as a viable alternative to brick wall, it captured as much as 20 percent of the market at some places [56].

In 1980s and 1990s, the techniques for designing and building in rammed earth evolved at rapid rate. This evolution refers to a wider use of off-site soils, successful application of stabilizers, improved forming systems and an increased awareness of the environmental and thermal benefits of thermal mass walls.

At that days, a challenge for further penetration of rammed earth technique in building market was to overcome its relatively slow construction process. For that reason, PISÉ (Pneumatically Impacted Stabilized Earth) process was developed by David Easton, in which properly selected soil materials are conveyed through hoses with high pressure air and impacted against a one-sided form work [61].

In the last decade, technology of rammed earth has dramatically evolved by construction companies in USA, Canada and Australia. Sophisticated formwork and careful selection of soil for high aesthetics, placement of insulation inside the masonry, water repellent additives, pre-cast transportable stabilized rammed earth panels and even rammed earth masonry unit/block are some of the cutting edge technology in the sector. In addition, use of rammed earth in commercial projects has pushed the boundaries and efficiencies of the material to its present limits. In Australia, advancements of construction efficiency include the development of telescopic handling systems and formwork systems compatible with cladding portal frame steel structures. In North America commercial projects in very cold climates have necessitated the adoption of untried techniques for heating and hoarding. Indicative is the use of tent to accommodate building “indoors” or the development of soil blends able to survive in extreme temperatures (+40°C to -40°C) and abrupt changes in temperature and humidity [36].

Moreover, rammed earth builder’s associations have been spread especially in North America and Australia. Technical knowledge, solutions on typical problems arising in the local building context and even advice for incorporation of passive design strategies along with rammed earth techniques are their main practice.



4.3 Structural insulated rammed earth wall by Shirewall company



4.4 Pre-cast rammed earth panels by Rammedearthworks company



4.5 Rammed earth masonry block by Rammedearthworks company

Table 2

Summary of adobe's and rammed earth's characteristics.

	Adobe		Rammed earth	
	Advantages	Disadvantages	Advantages	Disadvantages
Structural capability	It is a simple structural solution for more sophisticated forms.	When unstabilized, it has to be applied with enough thickness for satisfying structural stability.	Reasonably high strengths can be achieved with stabilization and reinforcement.	
Thermal mass	1300 KJ/m ³ .k volumetric heat capacity.	It has to be applied with enough thickness for effective thermal mass.	1673 KJ/m ³ .k volumetric heat capacity, resembles a heavy weight masonry. Optimal for climates with diurnal temperature difference of at least 6°C.	
Insulation	In mild climates insulative properties may be satisfactory.	Insulation is necessary in majority of climatic types.		Insulation is necessary in majority of climatic types.
Moisture resistance	Stabilization enhances structural and hydric properties.	It is susceptible to moisture; its wet compressive strength is near zero.	New water repellent additives can waterproof walls right through.	It is susceptible to moisture.
Sound insulation	Good sound insulation properties, resembling monolithic masonry structure.		Superior sound insulation properties.	
Fire and vermin resistance	Excellent fire and vermin resistance.		Excellent fire and vermin resistance.	
Environmental impacts	Traditional adobe's embodied energy is near zero and is fully recyclable.	Use of highly processed additives, extensive mechanization and transportation increase embodied energy and decrease recyclability.	Traditional rammed earth is a low greenhouse gas emission product with low embodied energy and fully recyclable.	Use of highly processed additives, extensive mechanization and transportation increase embodied energy and decrease recyclability.
Buildability, availability and cost	It has great buildability and it is well-suited to owner-builder system.	It requires high labor force. Commercially produced adobes are even more expensive than brick veneer. Slow construction process.	It is worked directly on the foundation. Whereas rammed earth industry is well established costs are dropped.	It requires formwork. It requires high labor force. Slow construction process.
Developments			Pneumatically Impacted Stabilized Earth (PISE), sophisticated formwork, insulation inside masonry, water repellent additives, pre-cast transportable stabilized rammed earth panels, telescopic handling system, development of soils suitable for extreme climate conditions	

4.1.4 Code provision for earth building

In the past decades guidelines began to take shape for the earth wall building. Numerous of test results and data for a wide range of soil types have been accumulated. Standards for reviewing plan submittals and for inspecting the construction of earth buildings have been developed.

Earth building has gained trust by banks, with the approval of loans, by building authorities, with the issue of permission, and by building market, with the higher reselling price of earth buildings compared to conventional frame and stucco [62]. However, on general terms, code provisions have a long distance before earth building is considered fully and appropriately regulated.

In US, earth does not technically fall into any of the categories listed in the Uniform Building Code. However, the code does include adobe construction. It has to be noted, that since the adobe code was created in response to California's 1933 earthquake, building officials treated adobe masonry as it were concrete, disregarding its unique properties and characteristics. Hence, National Code requires vertical steel reinforcement within the adobe walls in all earthquake zone areas with seismicity greater than 1 (most of Western US).

In 1985 though, an earthquake simulator test, done by the University of California, Berkeley, showed that the strength-based engineering solution of vertical steel rod reinforcement, required by California's building codes, was not the only not even the optimal way to ensure adobe's stability against earthquake [63]. Unfortunately, the higher cost and effort required to comply with the national code standards almost ended adobe construction throughout California and other western states [40].

On the other hand, New Mexico has created its own adobe code, in which vertical steel reinforcements are not required. On the same direction, Arizona and Colorado, based their own adobe codes on New Mexico [40].

The use of adobe was also discouraged in Europe. In Germany, in the late sixteenth century, widespread deforestation forced governmental authorities to promote earth building. This resulted in tens of thousands of adobe homes being built in the eighteenth and nineteenth century [64]. At the same pace, in lack of transported or processed building material, thousands of earth-walled buildings were erected after World War I and II.

Unfortunately, despite of this encouraging tradition, in 1970 German building authorities banned the use of earth as structural element.

In 1944 though, the first Earth Building Code in Germany was issued, while the regulations were put into practice only after 1951 with DIN 18951. In 1998, the *German Foundation for the Environment* issued the “Lehmbau Regeln” including several technical recommendations, while two decades later, in 2008 a revised version was passed.

In Spain, in 1992, “Bases for design and construction with rammed earth” was issued in an effort to support not only rammed earth but also adobe construction in the country. Delgado et al., in their recent study on earth architecture in Spain, concluded that although there is a couple of earth building guidelines, earth is not included in the general building regulations, hindering the construction process and development of earth industry [65].

Australia was a pioneer on earth building as it was one of the first countries to have specific regulations on earth construction. In more detail, in 1952 Commonwealth Scientific and Industrial Research Organization (CSIRO) published the Australian regulations that were revised in 1976, 1981, 1987 and 1992. Recently, in 2002, the guidelines were replaced by the Australian Earth Building Handbook [66].

5 Barriers against further penetration of vernacular earth architecture into contemporary *sustainable building design*

Building with natural materials and vernacular techniques faces many challenges in modern world. Natural building techniques, vernacular techniques rooted back to our tradition, are largely neglected in developed or less developed countries, through institutional decision makers, government, educational institutes, banking and business, often considering them primitive, unreliable or inappropriate.

Challenges of Technology Transfer

Gain and transfer of vernacular construction technology faces many challenges. Firstly, in less developed regions, where vernacular techniques are to some extent still alive, such knowledge is often trapped within the community, as there is no profit incentive for dealing with low-income people [67].

Moreover, as with any field, true knowledge on a construction method comes along with training and hands-on experience. Unfortunately, formal education of architects and structural engineers as gained in the universities is restricted to mainstream, modern materials, most of them highly processed or costly, such as cement, steel, aluminum and fired brick [40]. On the contrary, there is limited or even no academic training on alternative natural building construction, the vernacular construction methods of our tradition, while in many cases training focuses only to the preservation of such buildings. According to Niroumand et al., only three universities offer earth construction courses; the University of Kassel, the University of Applied Sciences in Potsdam and the University of Weimar (Bauhaus) [66].

Furthermore, although many development projects promoting vernacular materials and construction methods have been launched, they face only temporary success. Such projects have often outside funding, thus when that funding is spent or if the leader of the project loses interest, quits or dies, the progress freezes and the knowledge is lost, if it is not well absorbed into the community by many people [67].

The aforementioned factors result in lack of expertise in the field, with only a small minority of engineers dealing with, enhancing and promoting vernacular techniques, trig-

gered by their own passion. The inclusion of vernacular building techniques in the educational programs of engineering institutions, along with the continuous funding of development projects promoting such techniques until they are deeply established in local community can face the challenge.

Challenges of Cultural Acceptance

Probably the prevailing factor for neglect and/or abandonment of vernacular, traditional building techniques is the unfounded prejudice that those are linked with poverty and poor performance. More specifically, questions and skepticism often concern earth building's cleanliness and durability, misconceiving that such buildings cannot withstand earthquakes and rain. In less developed regions, particularly, as people struggle for economical rise, prosperity and modernization, anything that is linked to the past is considered outdated, for poor, insufficient and/or nonfunctional [36].

In addition, as in a great part of the developed world, linkage with tradition is lost, vernacular techniques are considered new, undependable and under experimentation. The unwillingness to adopt such "unknown" construction techniques seems reasonable, especially considering that the low income person will probably have only one chance in life to build or buy a home. In such case, the experimentation with "ambiguous", unknown techniques constitutes an unaffordable luxury [67].

Often, such prejudice can turn into a marketing challenge; consumer education, demonstration projects and campaigns can be used to swift public opinion. For instance, a great step towards that direction is the use of vernacular/natural techniques in projects with high quality construction, safety and aesthetics to eliminate the bias that such techniques are for the poor [36].

Challenges of Usage

A barrier against the acceptance of vernacular techniques is their improper usage. Building techniques that haven't been applied properly, due to lack of technical knowledge and/or superficiality, result in failures. Such failures, raise the concerns and skepticism against the material itself, creating the false perception of poor performance. Common failures are due to raw earth walls placed on deficient foundation and under insufficient roofing, random mixing of soils for the formation of adobes, improper formation of openings etc.

For that reason, the development of educational programs along with the certification of expertise regarding both engineers and builders is necessary. Moreover, institutional technical control and supervision upon construction will restrain malpractice.

Technical data

Thermal and hydric properties of earth highly depend on available soils. Technical suitability of regional soil requires laboratory evaluation that comes with a cost. Unfortunately, not only alternative building workers have poorly organized trade associations, but also count on donations to finance research and documentation. The aforementioned factors result on limited available technical data on specific techniques, especially considering the technical evaluation of regional soils.

It is clear that the development of vernacular building techniques cannot be supported by donations of individual builders or customers, but large governmental financial support is vital to boost such industry.

In addition, such building workers and experts are not accorded with the respect and credibility that a highly-educated engineer is accorded, although most of them have acquired deep knowledge on specific techniques gained after decades of empirical practice. Unfortunately, such prejudice against the worker is wrongly reflected against the whole building technique.

Supply chain, workforce and costs

In the last decades, vernacular building techniques have been enhanced through research and experimentation conducted mostly by isolated builders or construction companies throughout the world. Pre-cast rammed earth panels, added insulation and specific waterproofing admixtures for raw earth walls are some of the new techniques that have been developed.

Unfortunately, companies and builders that hold such state of the art knowledge are limited, and such building practice often refers to high-budget projects. As low manufacturing costs accompany increased scale, if advanced natural techniques are to become more affordable, it is crucial that industries or clusters of industries around natural materials be created, technical knowledge be spread and supply chain be enhanced.

Moreover, vernacular building techniques require more time and workforce, a challenge for West modern economies. In order to become mainstream and go large scale there is one way; mechanization and prefabrication that comes with environmental cost. This is

the challenge for modern earth building in developed countries; ensure competitive construction quality, low costs and fast construction process, without sacrificing the potential environmental benefits of earth building (ensuring the materials retain a low embodied energy) [36].

Environmental benefits

One of the main advantages of vernacular/natural materials used in traditional techniques is their low embodied energy, as such materials are found/manufactured at short logical distance from the construction site or even on situ. Unfortunately, advanced process of natural materials in order to fulfil the optimal mechanical and hydric properties required by building codes, as well as contemporary construction practice often presupposes the separation of manufacturing and building site, let alone the transportation of raw materials from plantation or quarry and the insertion of highly processed additives. This requires more energy and less workforce, which means less social and environmental benefits. More specifically, as far as earth architecture is considered, soil stabilized with highly processed materials, undergoes a fundamental and irreversible chemical change. In that way, it is no longer recyclable [68]. A life cycle analysis could determine the acceptable degree of mechanization, additives and off-site resources according to environmental goals set by global community.

Code provision compliance, political willingness and contradictory interests

A major challenge for modern earth building is its compliance with code provisions, regarding mainly the high structural and insulative properties required by building regulations. Political willingness, along with deep understanding of earth's properties and standardization is vital, if earth techniques are to become mainstream. Unfortunately, according to Rael, R. lack and inappropriateness of building codes may hinder a political motive incited by large manufacturing companies. More specifically in his recent book *Earth Architecture*, Rael, R. states;

“Increasingly, it is illegal to build with earth because of building codes that are enforced by municipalities. While these decisions are made in the name of safety, it is more likely that manufacturers of industrialized products have lobbied to prevent the use of a free and versatile material such as earth.” [69]

Policy makers can promote the development of earth industry not only by developing appropriate building codes but also by taking specific strategic decisions. For instance imposing environmental tax for less environmentally friendly materials or setting higher

standards regarding material's embodied energy, durability and toxicity can constitute earth a first choice material at once.

Low involvement by natural building industry

Despite the aforementioned challenges, vernacular traditional techniques encounter a renewed interest by the worldwide building industry thanks to their potential low environmental impact. It is noteworthy that, such an interest is not accompanied with the respective involvement in natural building industry, as noted by Niroumand et al regarding earth architecture. In their study they concluded that there is a significant gap between interest and involvement level on earth building and earth architecture in various countries [70]. This gap enhances uncertainty, hesitation and mistrust on vernacular techniques freezing their development.

Table 3

Challenges against earth building's penetration into contemporary building practice

	Challenges	Actions
Technology transfer	<p>In countries where earth building traditions are still alive, technology is trapped within the community.</p> <p>Vernacular construction methods are excluded from educational programs of engineering institutions.</p> <p>Development projects promoting vernacular materials face temporary success, due to limited funding and loss of interest.</p> <p>Lack of expertise regarding engineers and builders.</p>	<p>Inclusion of vernacular techniques in formal engineering education. At an equal proportion with other mainstream highly processed materials.</p> <p>Continuous funding of development projects promoting vernacular techniques until the deep establishment of techniques in local community is accomplished.</p>
Cultural Acceptance	<p>In developing countries there is an unfounded prejudice that vernacular techniques are linked with poverty and poor performance.</p> <p>In more developed countries, vernacular techniques are considered, new, undependable and under experimentation.</p>	<p>Consumer education, demonstration projects and campaigns.</p> <p>Use of vernacular techniques in high quality projects, in terms of energy performance, safety and aesthetics.</p>
Usage	<p>Improper usage of vernacular techniques due to lack of technical knowledge and superficiality.</p>	<p>Appropriate education, institutional technical control and supervision.</p>
Technical data	<p>Lack of technical data, research and documentation.</p>	<p>Governmental funding for the development of vernacular building techniques.</p>
Supply chain, workforce and costs	<p>Research and state of the art technology is hold by isolated companies, supply chain is restricted hence costs are increased.</p> <p>High workforce and slow construction process.</p>	<p>Development of natural building industry, spread of knowledge and enhancement of supply chain to drop costs.</p> <p>Prefabrication and mechanization, without sacrificing environmental benefits.</p>
Environmental benefits	<p>Use of highly processed additives, mechanization, and use of off-site resources restrict environmental benefits.</p>	<p>Life cycle analysis for the acceptable degree of mechanization, additives and off-site resources.</p>
Code provision compliance and political willingness	<p>Lack and inappropriateness of building codes, ignoring earth's properties.</p>	<p>Political willingness, development of reasonable building regulations and standardization.</p> <p>Imposition of environmental tax.</p> <p>Setting of higher environmental standards for construction materials.</p>

6 Application of vernacular earth building techniques in contemporary building context

Earth architecture implemented with one of its two basic techniques, adobe and rammed earth, presents an increased interest in contemporary context, as has been already mentioned. It is noteworthy that, although many projects that incorporate earth architecture in building envelope have been completed, actual data on building costs, source of materials and thermal behavior of such buildings are rare, making research extremely difficult. However, investigating the worldwide contemporary building practice, three main categories of earth architecture projects (with rammed earth and adobe) can be spotted;

- a. High and standard budget; focus on passive design strategies and state of the art materials
- b. Owner-builder type; economic constraints and environmental consciousness
- c. Societies on crisis

6.1 High and standard budget; focus on passive design strategies and state of the art materials

In the first category, high and standard budget projects are encountered. Isolated construction companies, active mainly on North America, Canada and Australia for rammed earth and West America and Australia for adobe, hold state of the art knowledge, run extensive research and experiment on the continuous development of earth techniques. Moreover, highly educated engineers, sensitive on bioclimatic principles and green design, offer designs with high aesthetics and integration of passive solar techniques for optimal thermal performance and energy efficiency of the building.

Projects of this category are usually large single family houses on proprietary land, that present complex, contemporary plan, sophisticated forms and many passive design strategies. Building's envelope encounters abundant openings and high tech fenestration to exploit solar radiation. Unfortunately, only a limited high-salary clientele can afford such services, for houses that comprise unique aesthetics and high standards.

Moreover, state of the art technology necessitates the engagement of only advanced, highly expertise builders, excluding the contribution of local builders in the construction process. Under these terms, social benefits for the local community and economy are limited compared to vernacular earth techniques that boost the whole community.

In addition, environmental benefits are of question. Sophisticated plans and extravagant forms challenge earth's structural stability, requiring structural steel or concrete bonding systems. State of the art earth techniques, developed to meet contemporary construction requirements in terms of time, mechanical and thermal properties result in materials with higher embodied energy, since cement or other additives as stabilizers are used, added transportation is required and extended mechanization is applied. Hence, although the final product, the building, may be energy efficient, that means it has optimum thermal performance and reduced energy costs, the embodied energy of the construction materials is uncertain [36].



6.1 “Caterpillar House” with rammed earth walls designed by Feldman Architecture in California



6.2 Net zero residence with rammed earth walls designed by Noel Cross+Architects in California



6.3 Rammed earth residence that generates its own energy designed by Steffen Welsch Architects in Australia



6.4 Palo Alto residence with rammed earth walls designed by Cass Calder Smith in California



6.5 Residence with unstabilised locally made adobes designed by ONE EARTH DESIGN and Joaquin Karcher in New Mexico



6.6 Vineyard residence built with rammed earth walls designed by John Wardle architects in Victoria, Australia



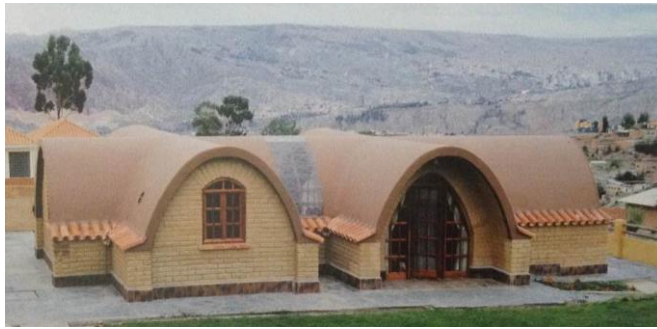
6.7 Crystal Waters Eco house in Conondale, Australia



6.8 Unit One; solar adobe residence designed by William Lumpkins in New Mexico



6.9 Adobe residence built by Earth Block Inc. in Colorado



6.10 Residence built of hand-made adobes, designed by Raul Sandoval in Bolivia



6.11 Adobe residence designed by Peterson D.

6.2 Low budget, owner-builder type

The second category, extensively prominent in developed countries, incorporates the use of earth technologies in an owner-builder system. In such projects, owners are highly motivated by environmental and economic incentives.

In earth building, raw material and production costs are marginal, while the majority of costs refers to increased workforce. In the owner-builder system, the owner participates actively in the building process; firstly to reduce construction costs and secondly to fulfil his inner environmental/ sustainable motif. In that way, construction costs may be reduced significantly.

An indicative example regarding costs and labor is adobe, a technique not a priory cheap, as labor to install the brick walls is quite high. According to Schroder and Ogle-tree, an adobe brick construction which includes insulation is estimated at about \$100 per linear foot in USA. Bearing in mind that a complete wall system ranges from \$53 per linear foot for timber frame with straw-bale and \$135 per linear foot for 14 in. Ras-tra (a brand of insulated concrete forms) adobe masonry is above standard. In cases though, where owner can participate in the construction process of adobe brick walls, cost can drop down by at least 15% [71].

Projects of this category are mainly medium to small size single family houses, with conservative plan and moderate size of openings. Aesthetics vary as they highly depend on owner's and builder's ingenuity. Although, not as impressive as high budget projects, a decent outcome can be achieved with plans and forms closely linked to materials' properties and construction restrictions.

Moreover, social benefits are increased, especially since local builders are engaged in the construction process. Building's performance may vary depending on the involvement/technology of the owner, and the inclusion of expert engineer or builder in the process. In cases, where there is a lack of technology by owner or builders, failures may occur.

When the main incentive for earth building is dropped costs, and owner doesn't hold in-depth knowledge of material, degree of highly processed stabilizers is of question. In cases though, where owner holds a high environmental consciousness, on site materials are mostly used with little or no addition of processed variants. In that way embodied energy of construction material is kept low.



6.12 Adobe residence built by owner-builder system in Mexico



6.13 Large adobe residence built by owner-builder system in New Zealand



6.14 Adobe residence built by owner-builder in USA



6.15 Rammed earth residence built by owner-builder system in Australia



6.16 Rammed earth residence built by owner-builder system in Pennsylvania, USA



6.17 Rammed earth residence built by owner-builder system in USA

6.3 Low budget, societies on crisis

Last but not least, earth techniques are extensively used in cases where cheap or low-skilled workforce is in abundance or/and a need for shelter is in urge. Societies on cri-

sis, in lack of financial means or technology resort to earth architecture, as the only affordable solution.

Architectural characteristics of such projects are almost primitive, identical in most countries, dictated by an economy of labor forces, resources and time. Rectangular plan, with a single door and limited number and size of openings is the norm, with variations depending on climatic region. Roof covering depends on cultural factors and scarcity of economical means, but corrugated zinc sheets or clay tiles are the most prominent (pic. 6.18, 6.19, 6.21, 6.22).

It is noteworthy that building with traditional earth techniques in societies on crisis, where workforce is in abundance with low or even no cost (voluntarism) can be a very economical solution. Although, economical and technical data are rarely available, an indicative example of a rammed earth project in Sudan suggests that a decent house was built at $\frac{1}{4}$ of the cost of a typical house (pic. 6.19) [72].

Moreover, such projects enhance social bonds within the community developing a feeling of collaboration and progress. Once an earth project is launched it constitutes an example for reproduction, while local technology is advanced and earth building network is developed.

However, during crisis, when a shelter is in in urge, considerations on environmental impacts may constitute a luxury. The extensive use of highly processed additives in the earth mixtures is common where lack of technology and knowledge of the technical properties of earth prevail. There are indicative examples where stabilization with cement at even 10% is applied (pic. 6.19) [72]. In extremely poor societies though, where transportation of highly processed stabilizers is not an option, earth techniques are actually used in their very traditional form.



6.18 Adobe for Women project in Mexico



6.19 Rammed earth project in Sudan



6.20 Rammed earth project in Botswana



6.21 Adobe house in highland area



6.22 Emerging Ghana project, house built of rammed earth in Ghana

7 Conclusions

The main objective of this study was to investigate whether vernacular architecture could be implemented in contemporary building context in terms of sustainability. Firstly, a literature review was conducted to investigate the factors that form vernacular architecture, the so-called superior energy efficiency of vernacular tradition and deficiencies of its approach by contemporary researchers.

It was concluded that there is not a determinant factor but rather a complex set of material and immaterial factors; geography, resources, climate, religion, ethics, family structure et cetera that formed our building tradition. Moreover, a great number of researches have concluded that vernacular residences correspond well to their specific climatic context, yet contemporary economic and social parameters as well as occupant's behavior may trigger the characterization of such constructions as sustainable. Finally, as far as contemporary approach of vernacular is concerned, a holistic integrated approach is necessary, avoiding arbitrary conclusions and generalizations, ensuring the inclusion of the three pylons of sustainability; economy, society and environment. That's the only viable way to promote the penetration of vernacular architecture into contemporary building practice.

Categorization of vernacular architecture based on Köppen's climate classification

Proceeding, since vernacular tradition is vast, the area of study was set for residential preindustrial constructions, with an emphasis on peasant societies, since they resemble contemporary socio-cultural and economic context the most. Rising interest for vernacular building tradition stems from its supposed optimal thermal behavior on different climatic challenges. For that reason, worldwide architecture was thoroughly investigated to spot basic techniques concerning syntax, morphology and construction encountered in different climatic regions.

The architectural features were analyzed implementing Köppen's climate classification, a novelty in vernacular architecture categorization. The aforementioned classification was selected, for its climate regions coincide with well-defined vegetation regions, hence enable the linkage of climatic variables to available building materials.

Starting from a general analysis of each climate zone, the climate method was set and worldwide vernacular practice was investigated. Specific, representative techniques cor-

responding to different climatic contexts were spotted, allowing the formation of a basic architectural typology for Köppen's classification. Typology in terms of *syntax*; sitting, planning and relation to ground, *morphology*; plan and shape and *construction*; walls, roof, openings is found to be aligned with bioclimatic design and strategies. Findings regarding vernacular building features, demonstrate that useful passive design strategies were really implemented in the past. This current research could be a starting point for a more in-depth analysis/categorization of vernacular features according to Köppen's climate classification and the production, for instance, of a bioclimatic design handbook.

Vernacular architecture in contemporary building design_ modern earth architecture

Proceeding, in order to investigate the application of vernacular techniques in contemporary building context, the research focused on earth architecture and its two most widespread techniques; adobe and rammed earth for masonry structures. Thermal and structural characteristics, moisture resistance, environmental impacts, availability and building cost, as well as new developments and code provision were researched based on bibliography and building associations.

As far as thermal characteristics are concerned, it was found that rammed earth and adobe have high thermal mass but poor insulative properties. They can be ideally utilized in climates with large diurnal variations to sustain interior thermal comfort, a practice aligned with aforementioned conclusions on vernacular typology based on climate. However, in microthermal, polar, highland and arid climates insulation is necessary, placed ideally on the outer part of the masonry to fully exploit thermal mass. State of the art technology enables the addition of insulation inside the masonry for high aesthetics in both parts of the wall. Moreover, earth masonry can be used effectively as internal feature in a well-insulated envelope, acting as useful heat storage battery.

Structural stability and moisture resistance highly depend on available soils, hence local technical analysis is necessary before construction begins. Rammed earth and adobe walls can be loadbearing for low rise structures but stringent contemporary standards constitute stabilization necessary. The blending of additives can highly improve rammed earth and adobe's properties but come at environmental and economic cost.

A rising of interest for earth techniques is evident by new developments in the field, such as pre-cast stabilized rammed earth panels, water repellent additives, insulation techniques, mechanization methods et cetera. Furthermore, earth builders' organizations

although in an infancy level, are rapidly developing especially in USA, Australia, Canada and Latin America. On the contrary code provisions, are slowly developing to incorporate earth as common building material.

As far as environmental impacts are concerned, they are highly influenced by the use of on-site resources, the addition of highly processed additives, the manufacturing level and the establishment of earth techniques in the region. A clear, determined and specified answer for adobe's and rammed earth's sustainability is not possible but depends on local economic, construction and social context.

Barriers against further penetration of vernacular earth architecture

Further penetration of earth vernacular architecture into contemporary building design faces many challenges. It was found that technological, economic, social and political constraints hinder earth architecture from becoming mainstream.

In more detail, one of the most predominant factors is the lack of technology and building experts. This stems from the exclusion of vernacular building techniques from educational programs of engineering institutions. The inclusion of the aforementioned techniques in engineer's basic education, at an equal proportion with other mainstream highly processed materials could be the answer.

Moreover, an unfounded prejudice and skepticism against structural stability, performance and cleanliness overshadows not only rammed earth and adobe but the whole vernacular earth building techniques. It is suggested that the use of such techniques in high quality projects in terms of energy performance, safety and aesthetics can reverse such prejudice.

In addition, as far as economic constraints are concerned it was found that unless a local building network is well established and supply chain is extended, cost of earth techniques cannot be dropped. Moreover, unless highly manufactured such techniques are time consuming, which is a major drawback, non-compatible with contemporary building practice.

Finally, political willingness to recognize and promote earth as a building material appropriate for contemporary construction is of supreme importance. The inclusion of earth techniques in code provisions, standardization, specific technical guidelines, environmental taxes and higher environmental standards can ensure further penetration of vernacular earth techniques.

Application of vernacular earth building techniques in contemporary building context

Projects incorporating adobe and rammed earth techniques as loadbearing masonry features were researched, to fully understand contemporary earth building practice. It has to be noted though that a barrier against research was the fact that actual data concerning environmental, economic and social costs of such projects was almost impossible to be found.

Nevertheless, the study concluded that rammed earth and adobe techniques were used in three types of projects. The first category refers to standard and high budget projects, with sophisticated plan and morphology, and a focus on passive design strategies and/or state of the art techniques. The second category includes projects where an owner-builder system was applied, with more conservative plan and morphology, making such techniques a more affordable solution. The third category refers to projects where a shelter was in urge and no other solution was possible. In these projects, plan and morphology highly resemble primitive vernacular architecture. The simplicity and primitiveness of plan, along with low/no labor cost is reflected on its low budget.

The study concludes that earth architecture was not a profound sustainable solution for each project, since design, location, availability and use of resources, technology and involvement of local builders in the construction play a vital role. In that frame, each category suffers at least on own of the three pillars of sustainability. In the contemporary context though, it can be suggested that earth techniques can be a sustainable solution for societies on crisis, where building industry is not set, and local community is more flexible/willing to make those techniques large-scale. With the right education, vernacular earth techniques can offer economic, social and environmental benefits for the whole community.

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Appendix

Images and Tables citation

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3.A2 [Köppen Climate Classification (b)]. Retrieved May 24, 2018 from http://www.cengage.com/resource_uploads/downloads/0495555061_137431.pdf

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